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The BiBlade Sample Chain and Experimental Results for Comet Surface Sampling

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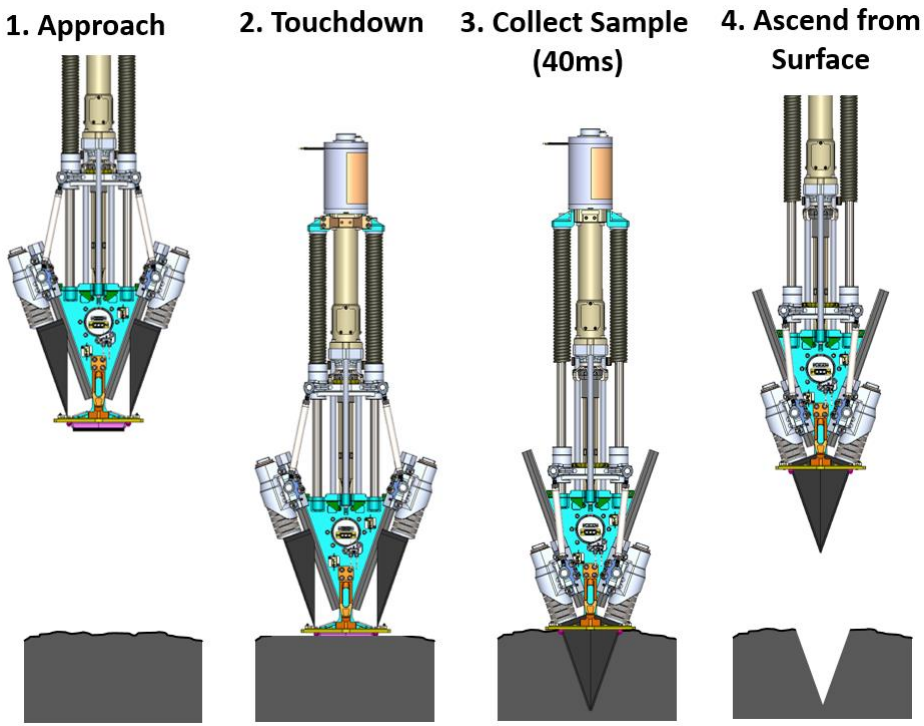
Touch-and-Go Mission Concept Architecture

- Spacecraft maneuvers to several meters from surface of comet.
- Sampler is at end of robotic arm.
- Spacecraft descends until sampler contacts surface of comet.
- Acquire sample.
- Ascend away from comet.



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Comet Surface Sample Return Requirements from the Decadal Survey

Group 1: From the Decadal Survey Primary Document

- Return a single ≥ 500 cc sample from the surface of any comet nucleus
- Preserve sample complex organics (sample using a “soft” technique)
- Prevent aqueous alteration of the sample at any time (maintain at ≤ -10^{o}C)

Group 2: In Decadal Survey Appendix Mission Study Document

- If the sampled region has shear strength <= 50 kPa
  - Return material from depth >= 10cm (~3 diurnal thermal skin depths)
  - Maintain sample stratigraphy
- Determine whether the sample is from an active or inactive nucleus region

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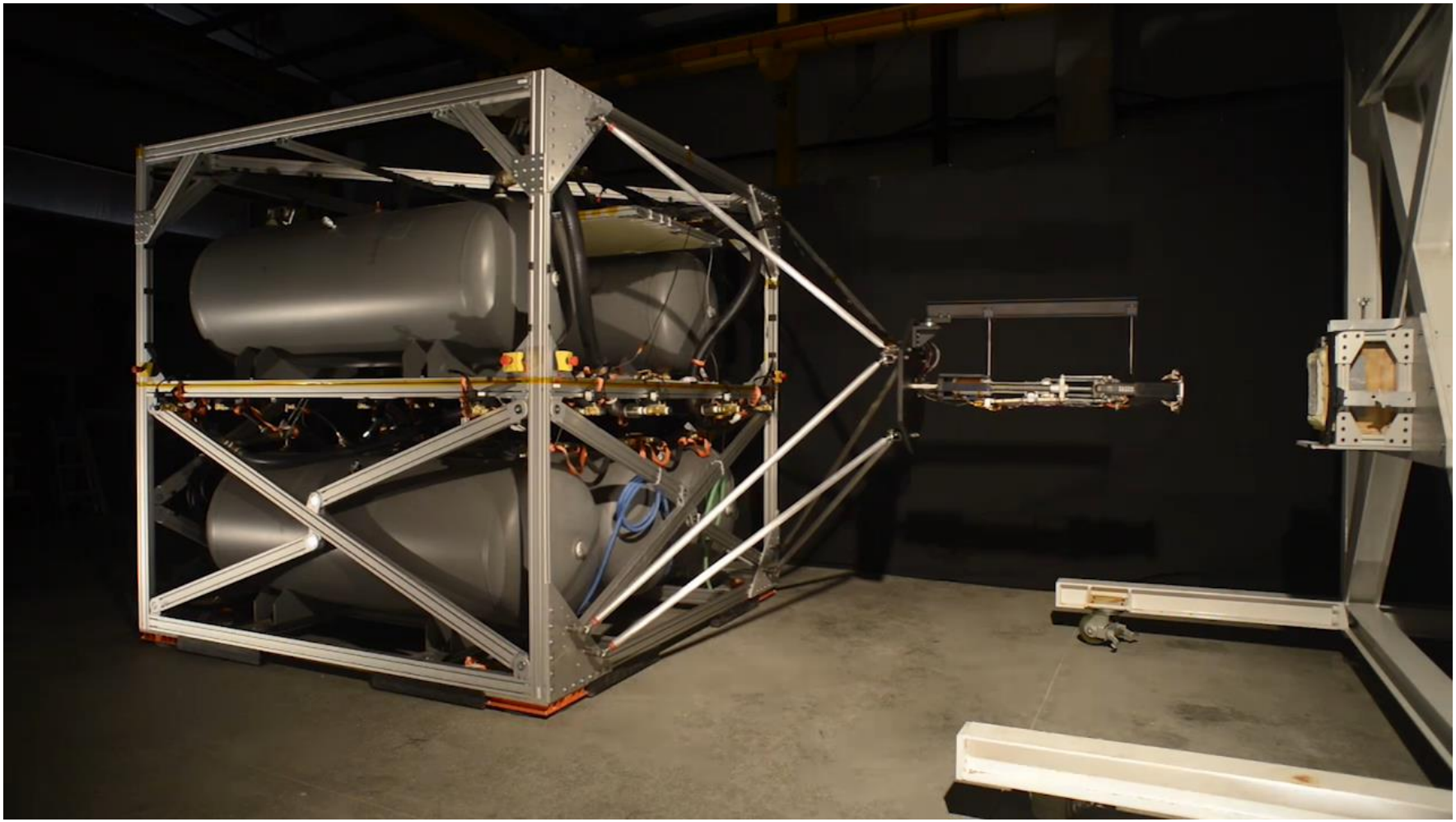
Full-scale Sampling Validation



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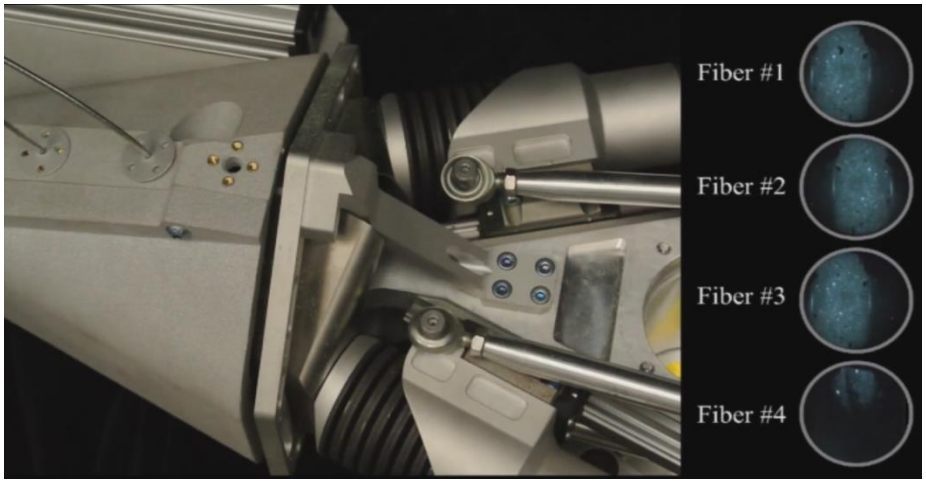
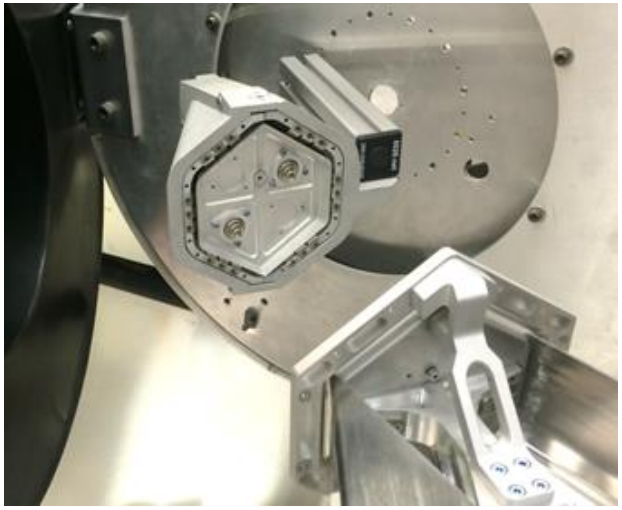
Sample Chain

Pull blades back compressing springs (one actuator for all operations)

Sample in ~ 30 ms (fast) and retract (tapered blades prevent binding)



Insert into sample measurement station and image with 9 fiberscopes



Insert into SRC and release lid via frangibolt (repeat for second sample)

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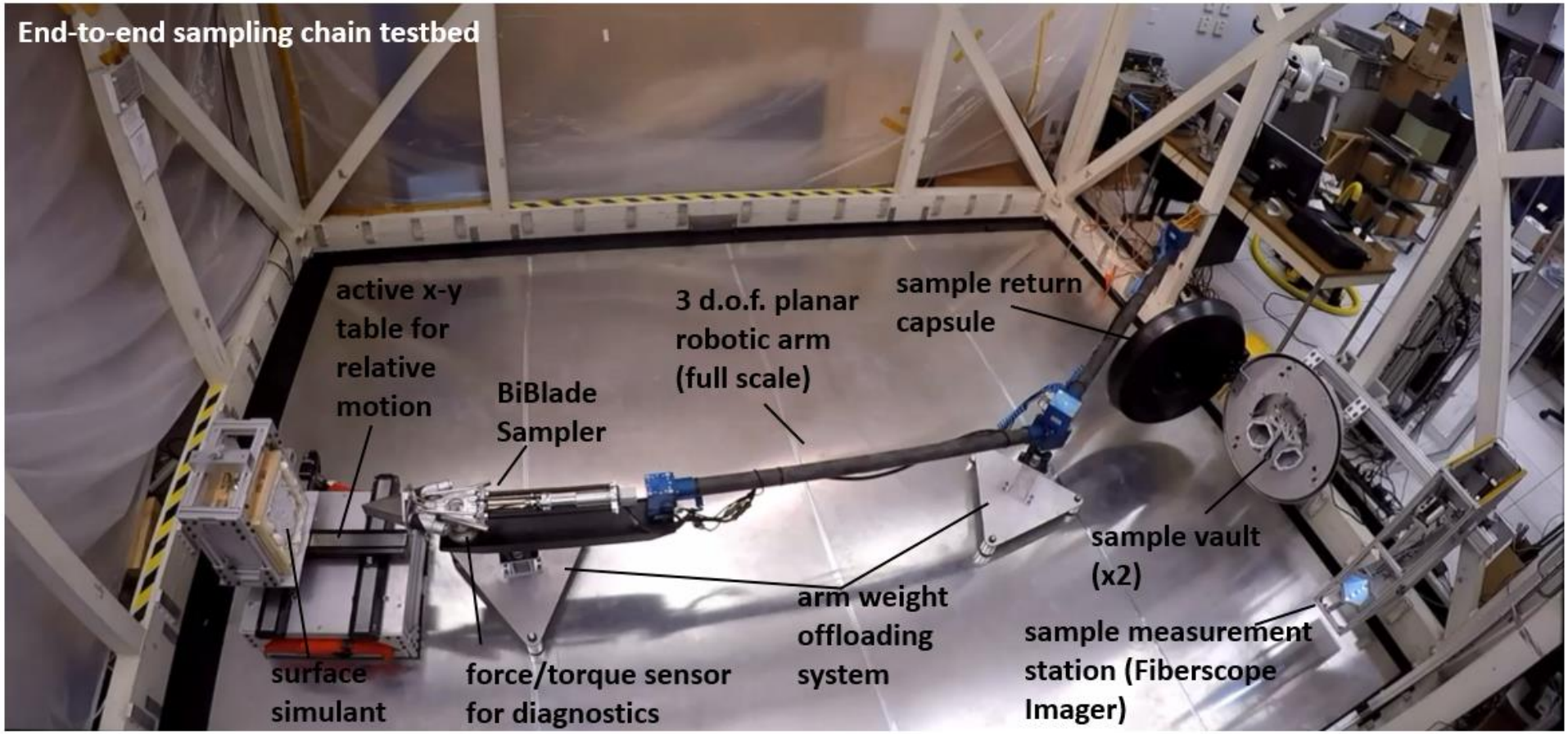
End-to-end Sampling Chain Testbed



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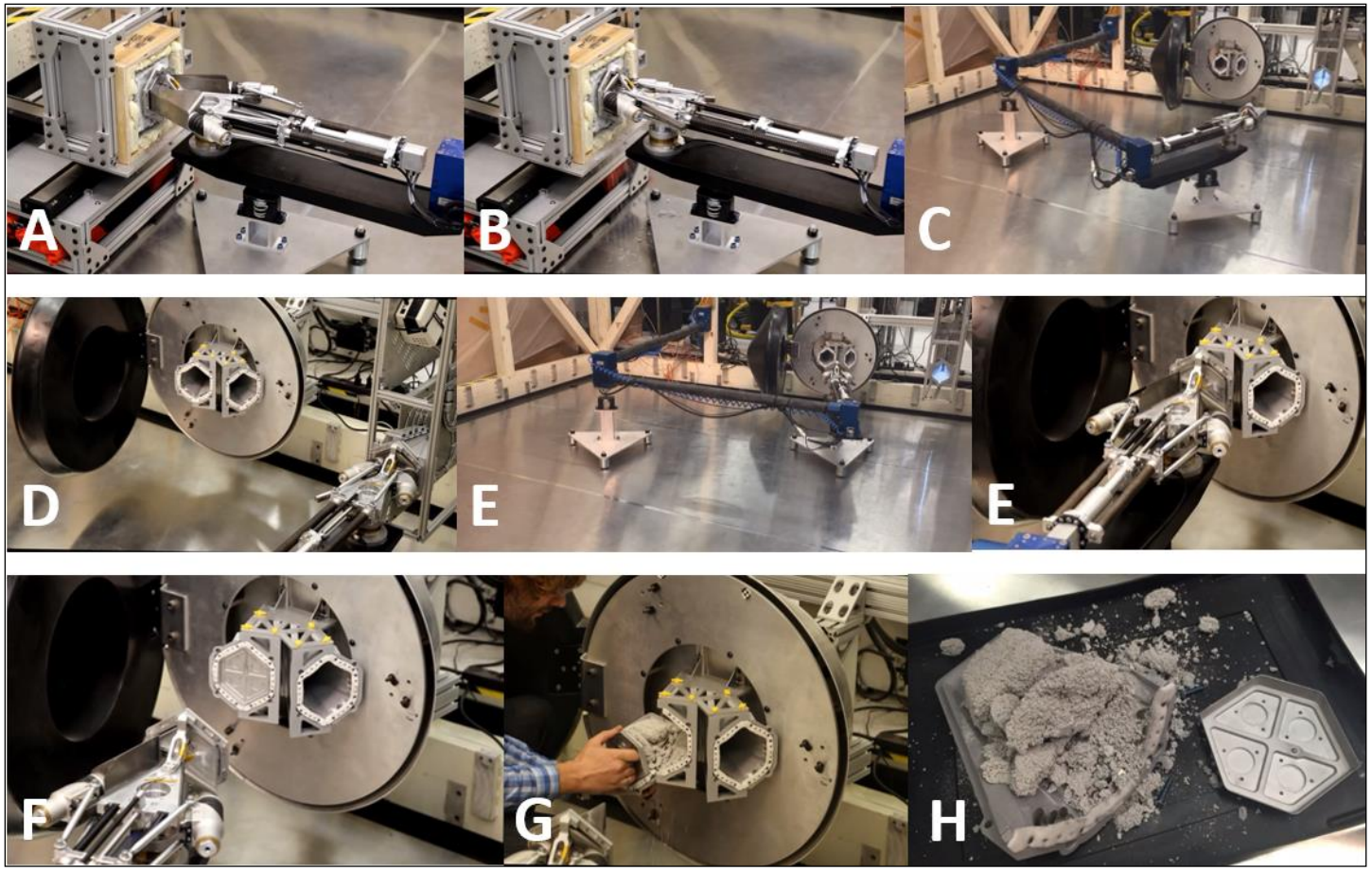
BiBlade Sampling Chain



(A) Approach; **(B)** Springs drives blades into simulant; **(C)** Transfer to Sample Return Capsule (SRC); **(D)** Sample measurement using Fiberscope Sample Imager; **(E)** Insert BiBlade into SRC vault and retract blades; **(E)** Fire Frangibolt to release lid and contain sample; **(F)** Retract; **(G) (H)** Show results by opening sample vault and displaying acquired sample.

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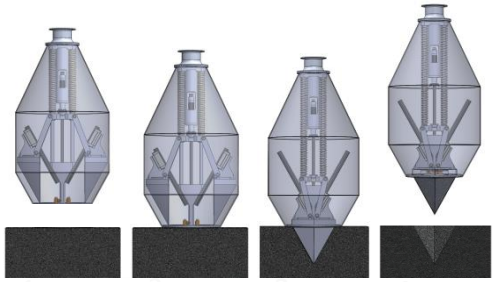
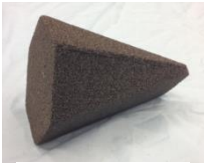
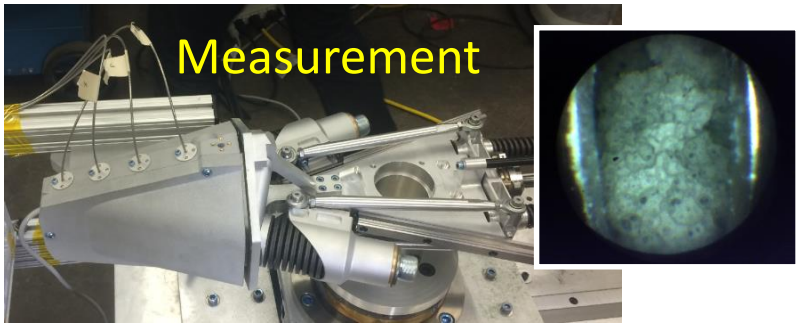
BiBlade Features

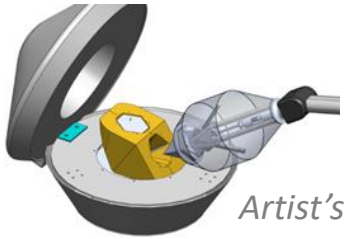
- Sample volume: 500 cc
- Depth: 10% below 10 cm
- Sample strength: 0 - 5 MPa CPR
- Sampling and encapsulation in ~40 ms
- Acquires and stores two samples from two separate sites
- Enables multiple attempts per sample
- Fully tapered blades for robust extraction from comet
- Direct measurement of sample with nine-fiberscope imaging
- Mechanically simple requiring only one actuator and two frangibolts







Insert into SRC



Artist's Concept

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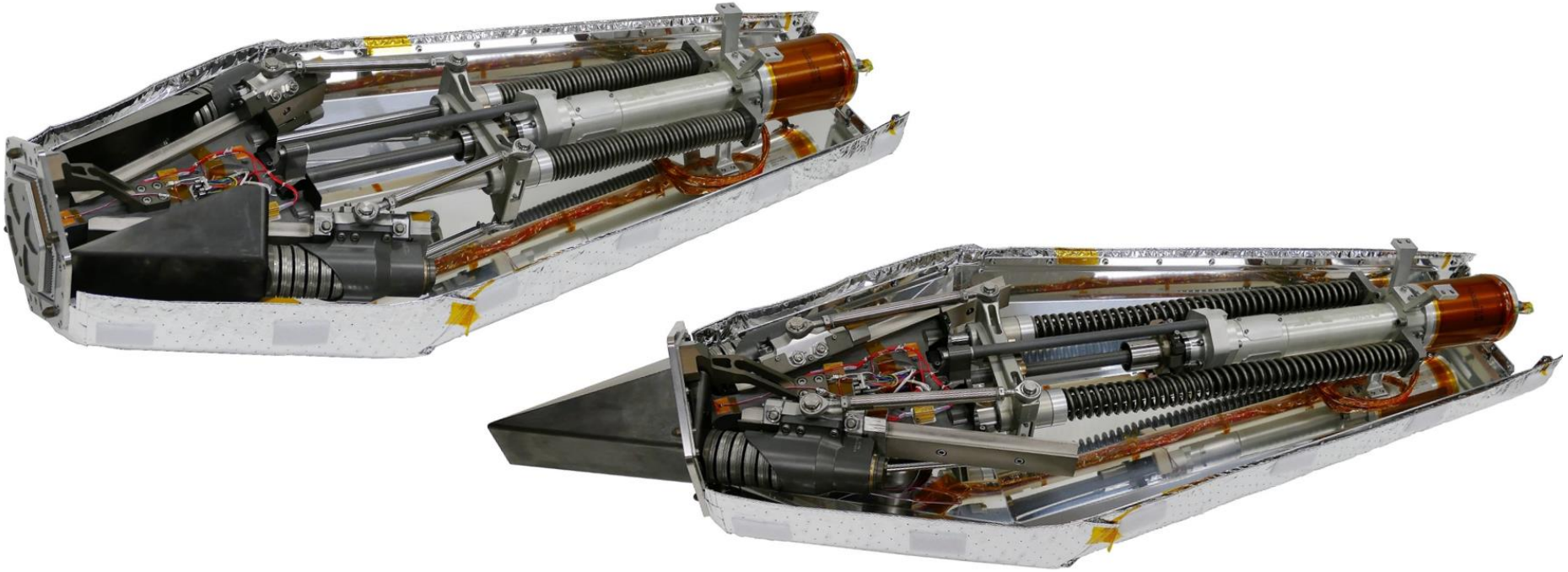
BiBlade Design



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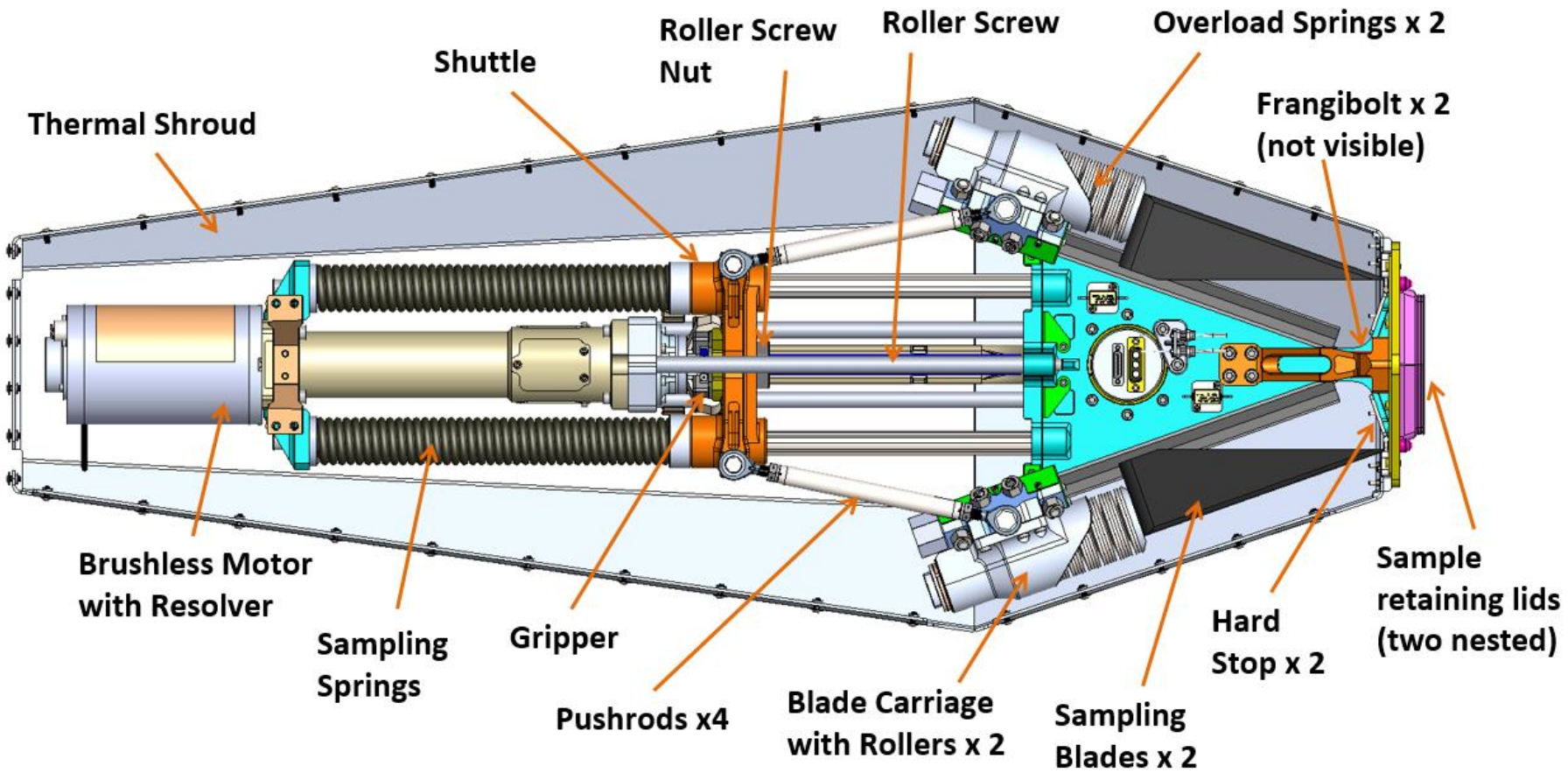
BiBlade Design



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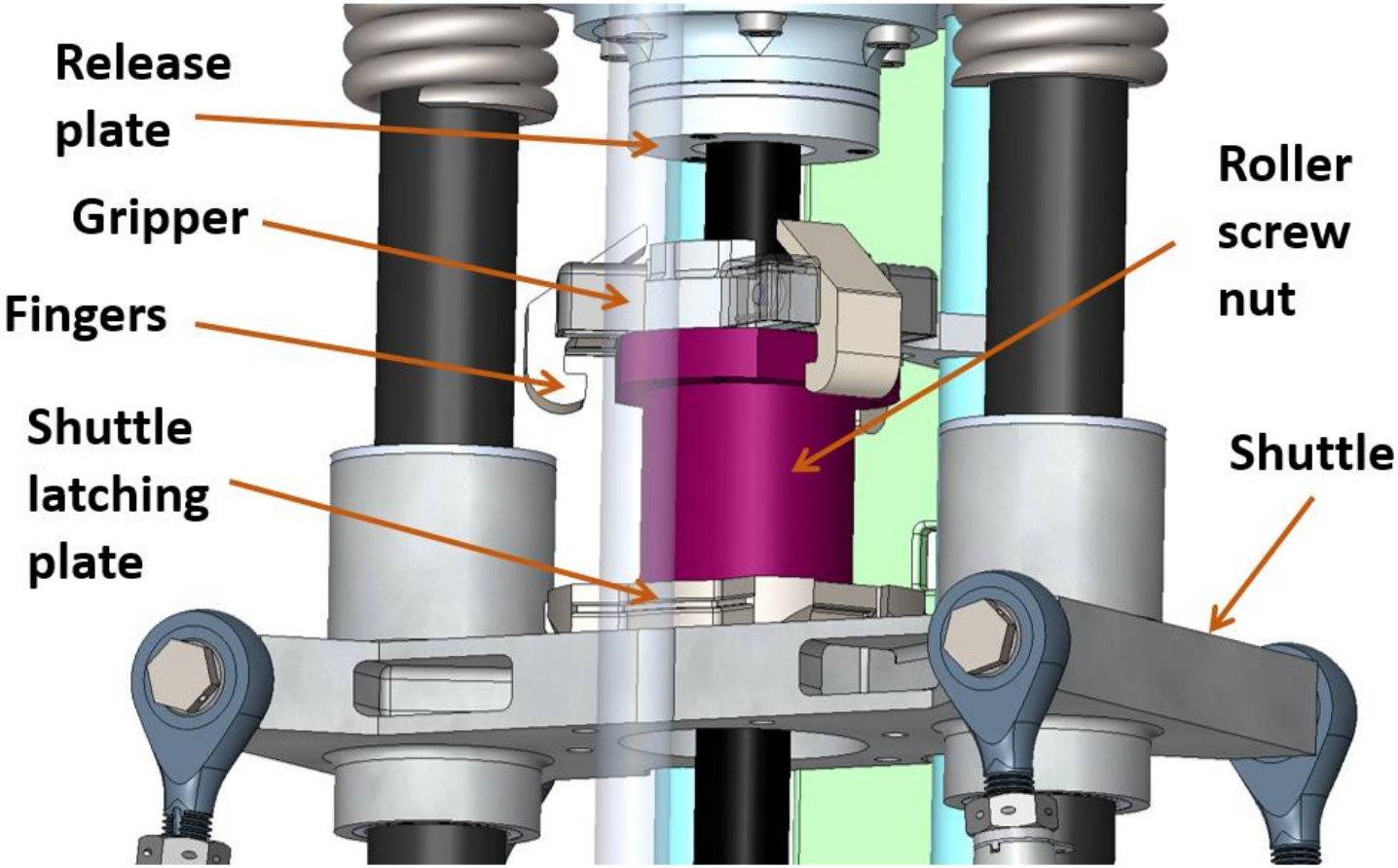
Gripper Mechanism



Mechanical Porous Ambient Comet Simulant (MPACS)

- Ingredients: Portland cement and pumicite combined and added to water and a foaming agent.
- Strength properties were varied by changing the amount of foaming agent added to the mixture.
- The MPACS material was fabricated into 8-inch cubic boxes for the BiBlade test program.
- Density, cone penetration resistance (CPR), uniaxial compressive strength (UCS), shear strength, and porosity were measured.

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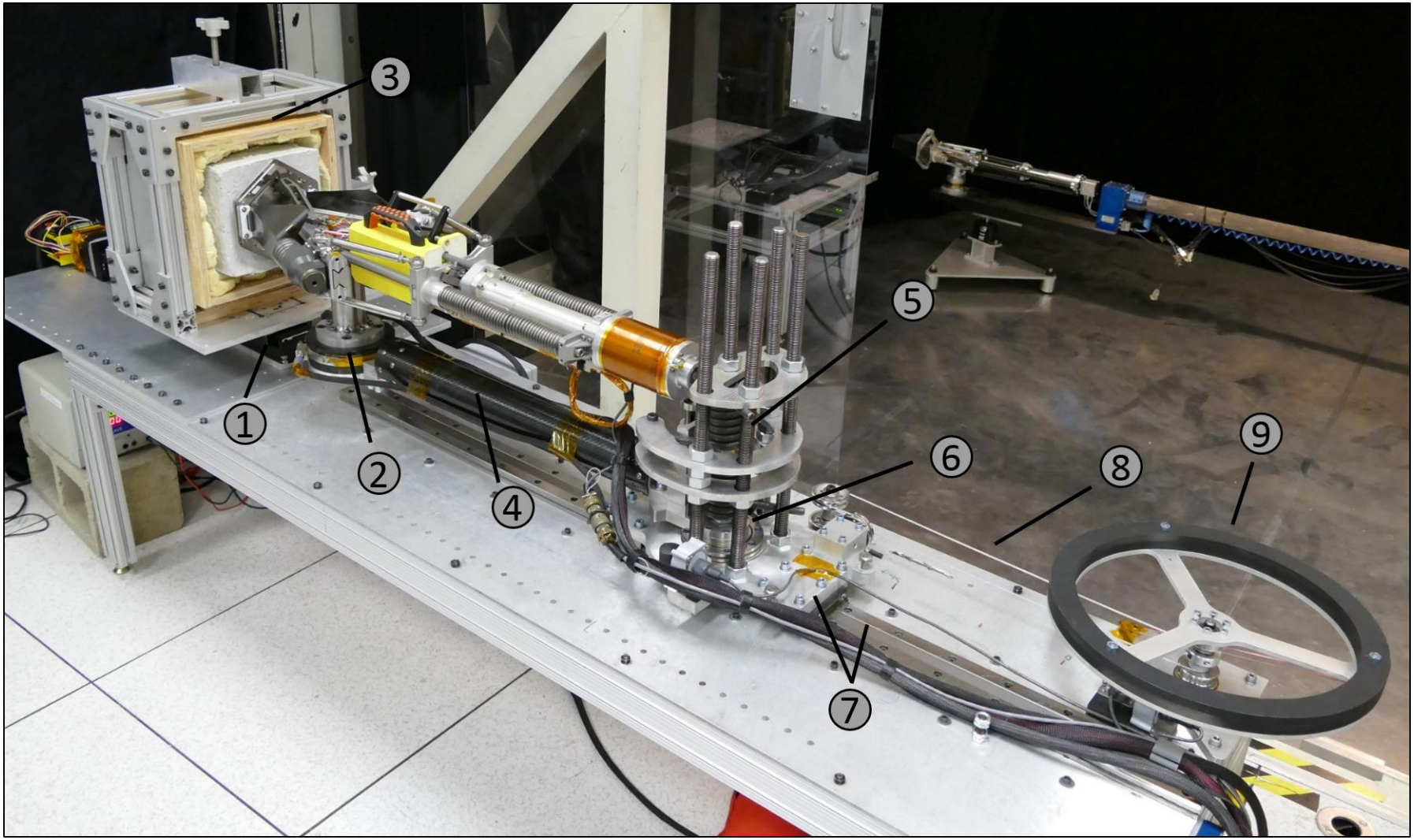
Sampling Testbed



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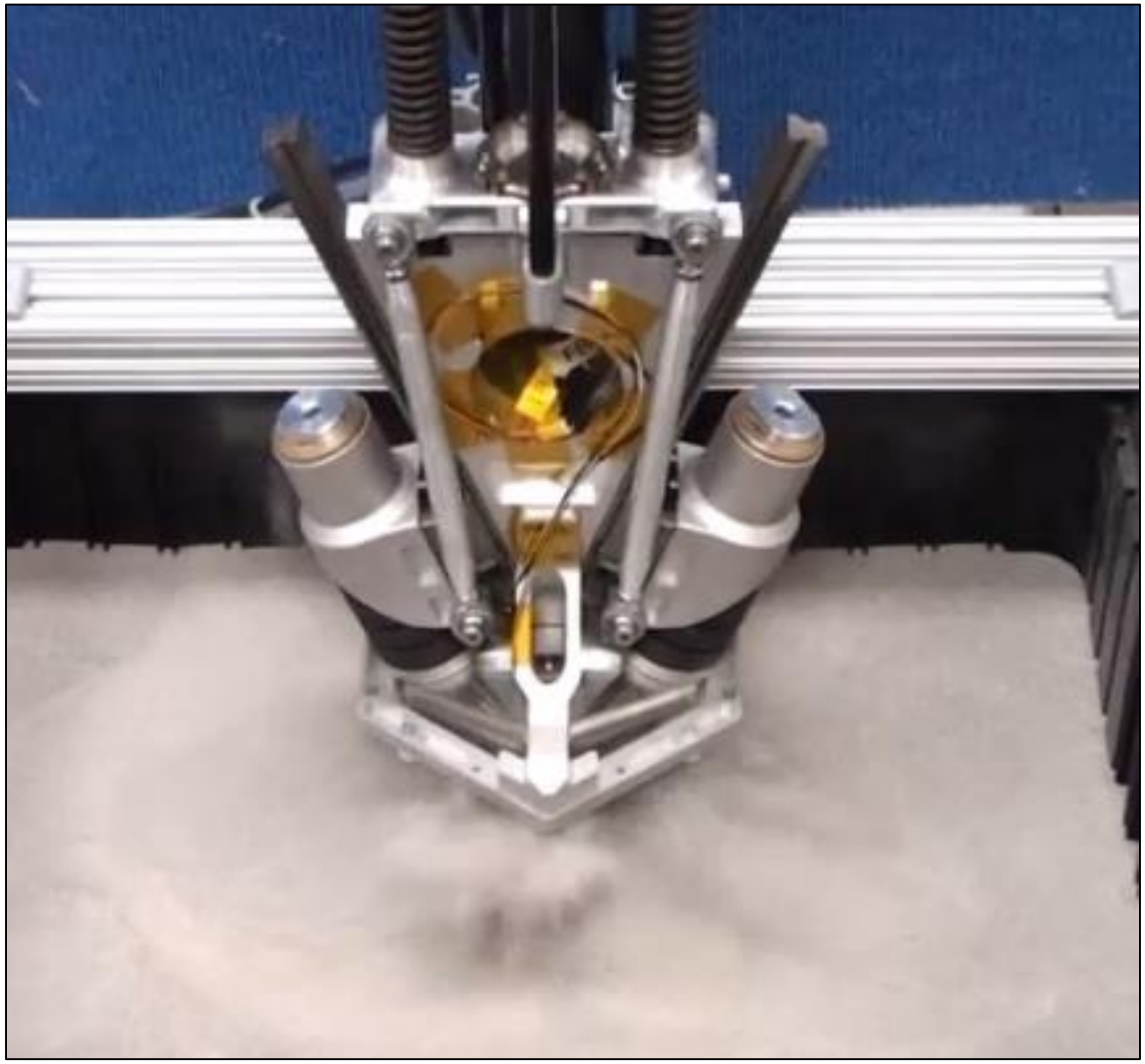
Low End Sampling Results – Sampling Into Fly Ash



- Ejecta plate redirects ejecta to the side, away from spacecraft

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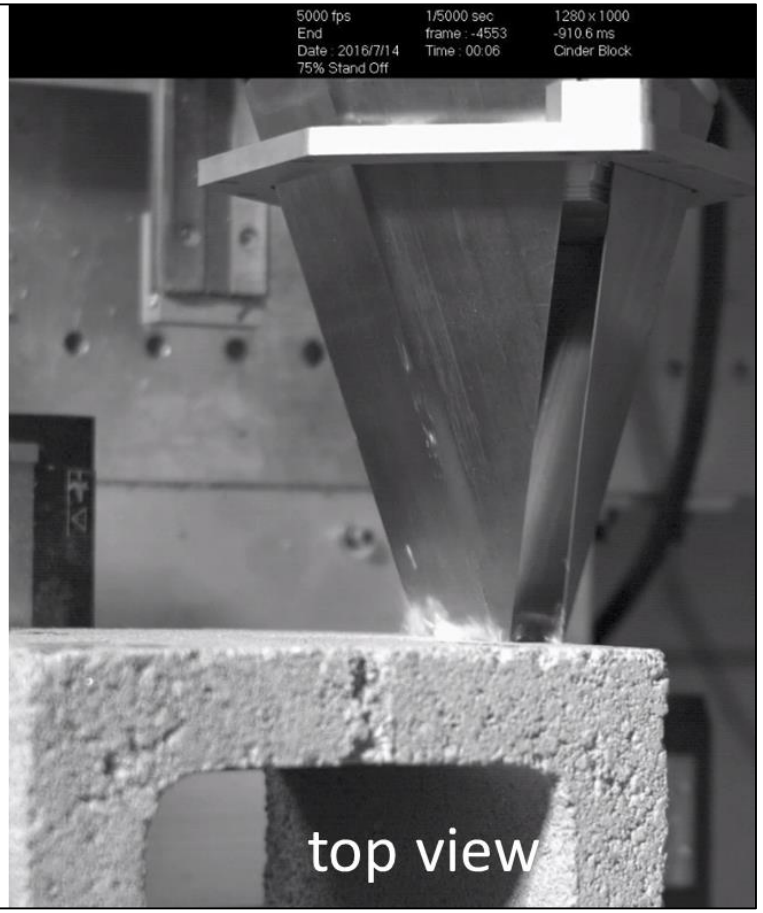
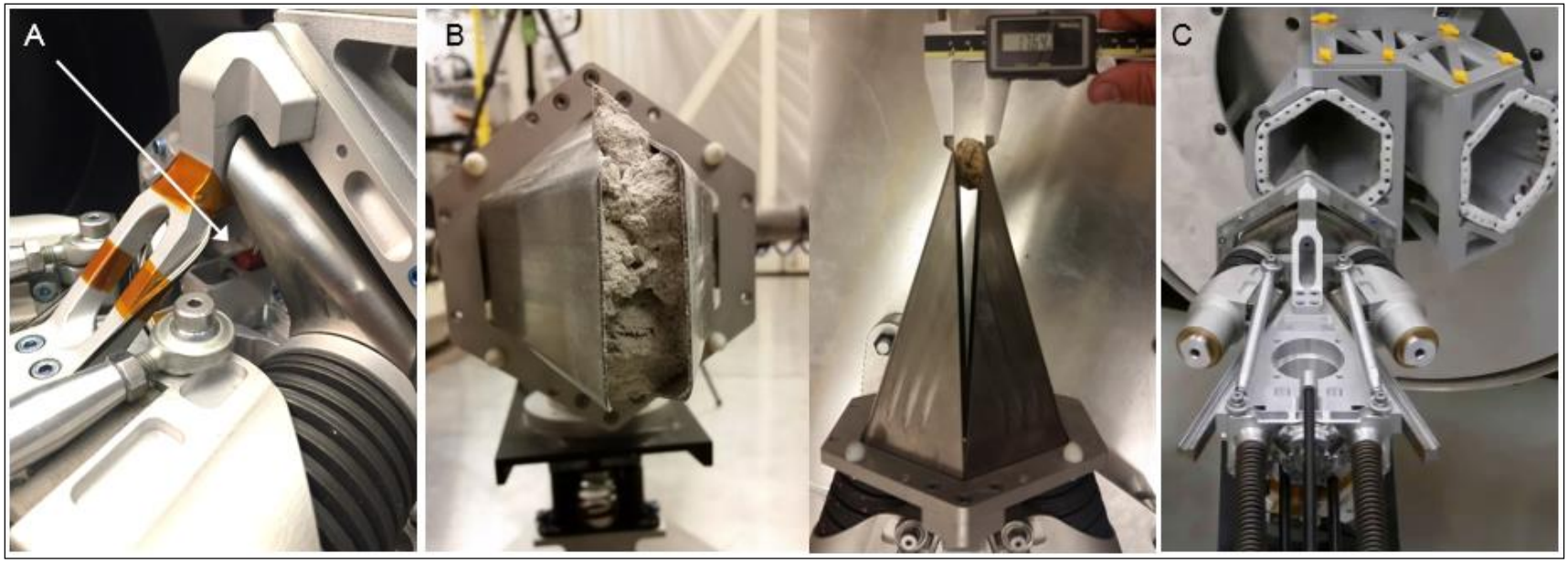
Survive Hitting Hardest Material

Tool survives hitting cinder block at maximum blade velocity, having only one blade strike. Overload springs absorb impact energy.



Robustness to Off-nominal Samples and Transfer Conditions



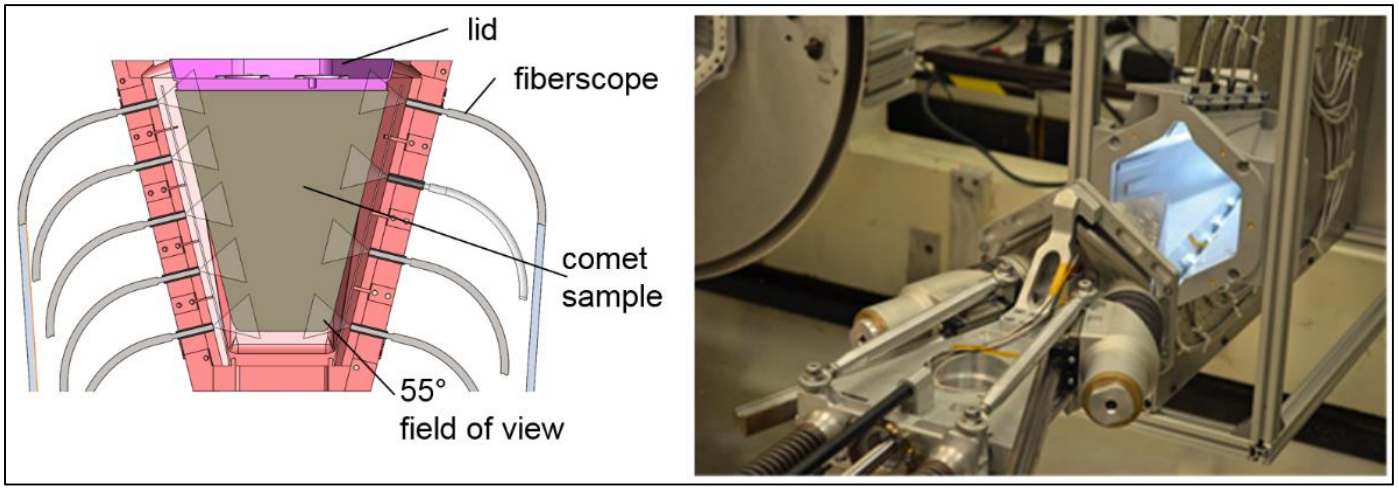
Robustness testing of sample transfer process/hardware.

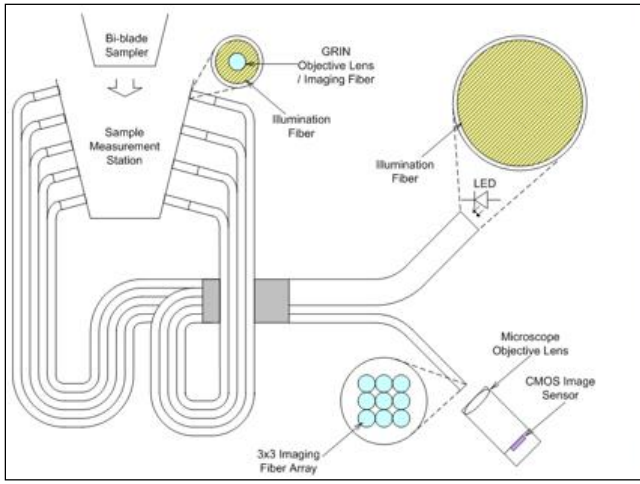
(A) Frangibolt actuation is included in the sample lid release.

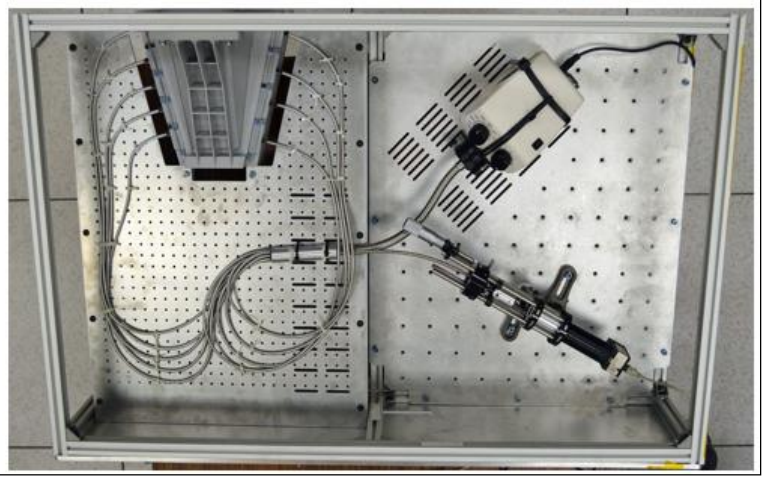
(B) Off-nominal samples are forced to test insertion and stowage robustness to extreme scenarios.

(C) Positional error was intentionally commanded to evaluate limits of self-alignment during tool insertion.

Sample Measurement: Fiberscope Sample Imager







Nine fiberscopes along the walls of the measurement chamber passively transfer views of the sample surface to a common camera

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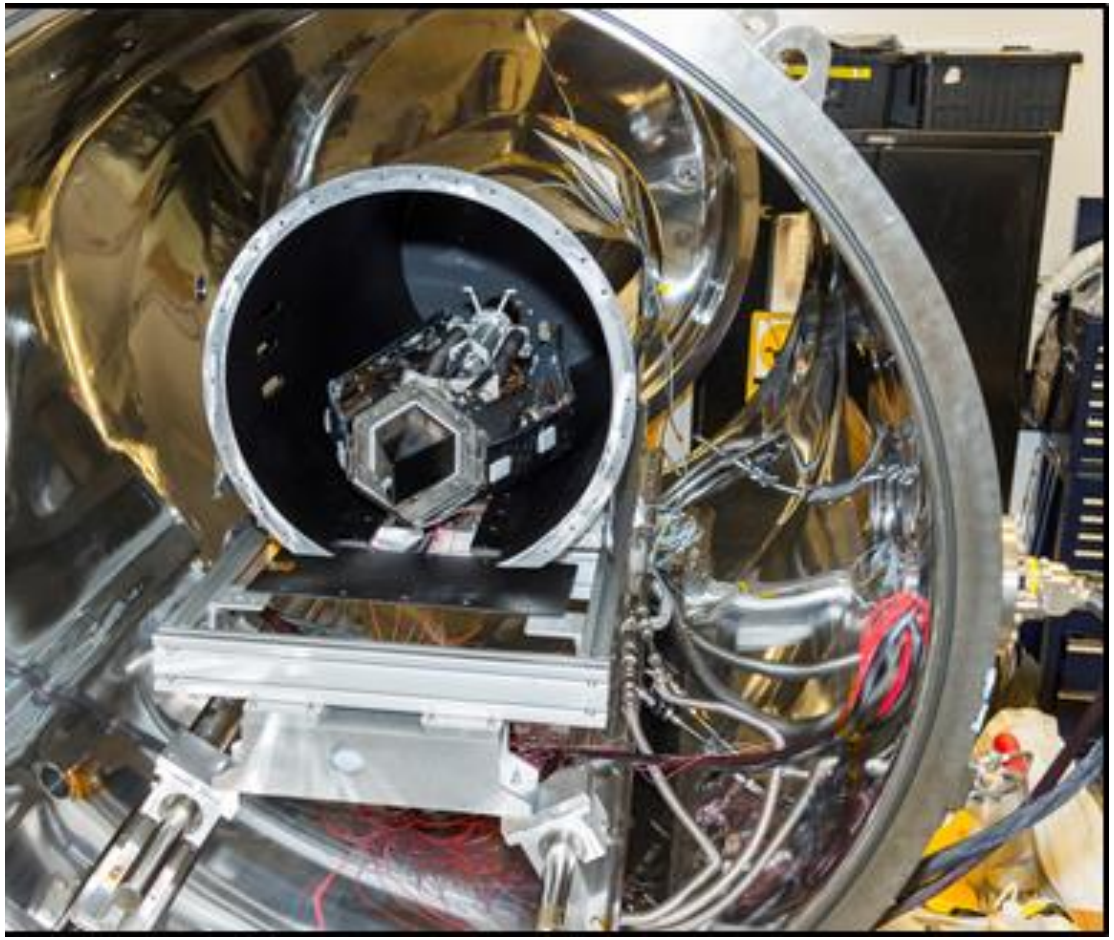
Thermal Vacuum Chamber Testing

- Cycling between +70°C and -160°C (three cycles)
  - Sampler thermal control system maintained cold phase tool temperatures between the thermostat set points, -32°C to -25°C
- Pressure 10^{-7} torr (high vacuum)
- Functional testing
  - Actuator homing s at each cold cycle
  - Functional test at last cold phase consisting of self-fire sampling operations five times
- Performance verification
  - Verify thermocouples read values within allowable flight temperatures of the components
  - Verify surfaces contacting sample (blades) do not exceed -25°C
  - Verify that actuator maintains adequate torque/current margin
  - Verify kinetic energy available for sampling (blade speed) within 5% of Standard Temperature/Pressure condition

Cold shroud end plate and top half of BiBlade thermal/dust shroud removed for photo.



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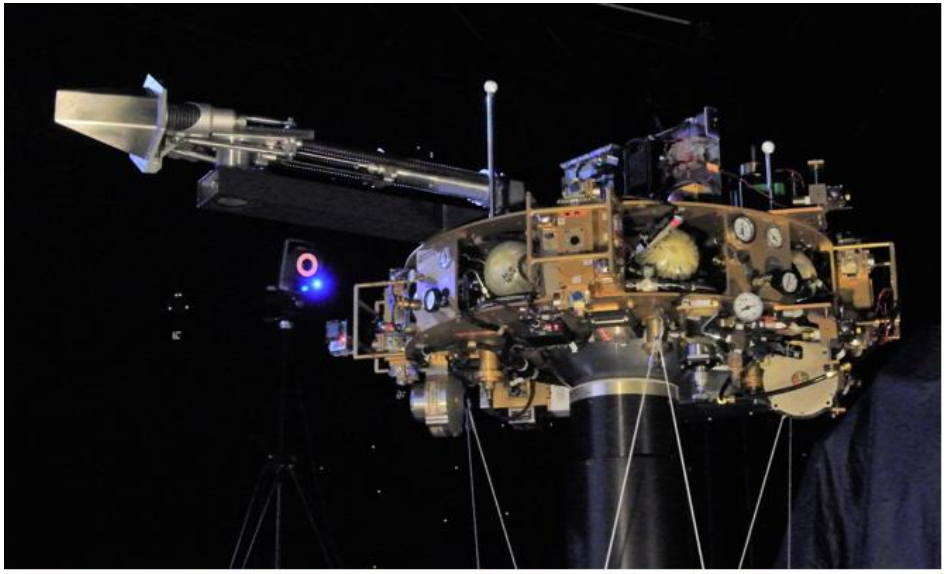
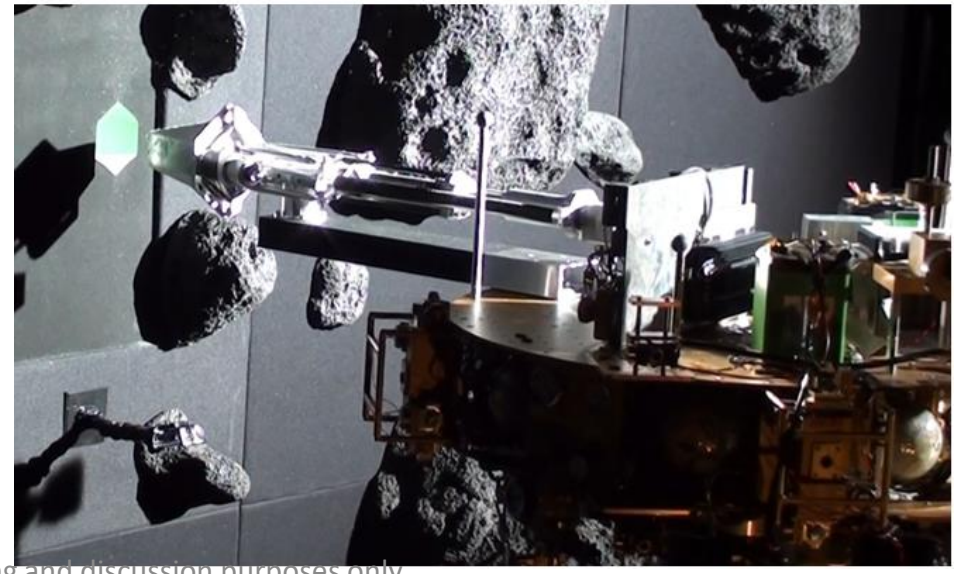
Integrated Proximity Operations and Sampling

- Mounted BiBlade on air-levitated robotic spacecraft and demonstrated autonomous Touch-and-Go approach, sampling, and ascent.
- In JPL Formation Control Testbed.





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